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ABSTRACT

FANTAB is a computer program written in Fortran IV which helps design factorial analysis of variance tables and provides formulae for table entries. It is a computerization of a paper entitled: "Rules of Thumb for Writing the Anova Table" (Millman and Glass, 1967). FANTAB is appropriate for factorial models which have two, three, or four factors, some of which may be nested. Input consists of factor names, factor types (random, finite, or fixed), and factor nestings (if any). FANTAB yields a checklist of input and analysis of variance table entries including: sources, sums of squares, degrees of freedom, mean squares, expected mean squares, and F-ratios. Appendices illustrate the main program and various examples of input. (Author/MV)

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FANTAB: A COMPUTERIZATION OF RULES OF THUMB FOR
FACTORIAL ANOVA TABLES

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Tufts University, 1968

U.S. DEPARTMENT OF HEALTH
EDUCATION & WELFARE
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APPROVAL PAGE

Master of Arts Thesis

FANTAB: A COMPUTERIZATION OF RULES OF THUMB FOR
FACTORIAL ANOVA TABLES

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1969

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ABSTRACT

FANTAB is a computer program written in Fortran IV which helps design factorial analysis of variance tables and provides formulae for table entries. It is a computerization of a paper entitled: "Rules of Thumb for Writing the Anova Table" (Millman and Glass, 1967). FANTAB is appropriate for factorial models which have two, three, or four factors, some of which may be nested. Input consists of factor names, factor types (random, finite, or fixed), and factor nestings (if any). FANTAB yields a checklist of input and analysis of variance table entries including: sources, sums of squares, degrees of freedom, mean squares, expected mean squares, and F-ratios.

CHAPTER I

INTRODUCTION

An article by Millman and Glass (1967) entitled "Rules of Thumb for Writing the Anova Table" gives a generalized procedure for determining formulae for entries in factorial analysis of variance (anova) tables. Given these rules and certain combinations of random, finite or fixed factors, one can list sources of variation and can write formulae for computing sums of squares, degrees of freedom, mean squares, and expected mean squares for each source. Rules are also given for forming F-ratios to test hypotheses about the sources of variation.

The authors stated that they hoped that mastery of their rules of thumb by potential users of factorial analysis of variance would encourage further and more appropriate use of these techniques. However, their article requires a great deal of study for mastery, and even for those who may read and fully understand the Millman and Glass article, the procedures are tedious, and there always remains the chance for human error. This writer feels that the Intent of Millman and Glass will be furthered by the following Fortran IV program, which yields anova tables according to their rules of

thumb. The program has been named FANTAB, short for Factorial ANova TABLES.

Some may ask, "What good would such a program be?" The best answer to this question is a story about the efforts of another program writer. It seems he had written a computer program to solve differential equations and was consulting a friend of his who was a mathematician. After checking several examples solved by the computer and finding no errors, the mathematician said, "Yes, these are right, but your program does not do anything that I can not do myself." This mathematician shows a lack of insight into the value of computer programs. Only through building on such programs will the maximum utilization of computers ever be approached.

While computerization requires that a potential user have access to a computer, this is becoming less and less of a problem. Familiarization with computer programming is not necessary for use of this program. If a computer center assistant can help a user keypunch from four to six data cards and get access to a system with Fortran IV capabilities, then use of FANTAB may be very easily accomplished. The format of the data cards will be fully explained below. A user of FANTAB should understand what an analysis of variance does and what interaction of factors means. This degree of familiarization with anova is not difficult to attain in a very short time.

CHAPTER II

DEFINITIONS AND ASSUMPTIONS

The following definitions of terms are the same as those used by Millman and Glass (1967) and are used to determine FANTAB's input:

1. Levels: Different categories of a factor are called levels. For example, if the variable "type of school" were chosen as a factor for an experiment, and we had two different types in mind, e.g. private versus public, then the category private and the category public are the two levels of this factor.

2. Crossed factor: Two factors are said to be crossed, rather than nested, if every level of one appears with every level of the other. For example, if one were interested in testing two teaching techniques in both private and public schools, then each technique would be tried at each type of school. The factors type of school and teaching technique would be thus crossed.

3. Nested factor: A factor is said to be nested within another factor if each level of the nested factor appears in only one level of the other factor. That is, a particular

level of a variable does not appear with all levels of another variable. For example, schools may be nested within type of school categories. No school belongs to more than one type of school category. Although there may be somewhat similar schools in the two type levels, they are not the same school. Thus the factor "school" is nested within type of school.

4. Random: A factor is called random if levels of that factor are a random sample from a large population of levels with normally distributed effects.

5. Finite: A factor is called finite if levels of that factor are a random sample from a finite population of levels.

6. Fixed: A factor is called fixed if all levels of a factor are in the study, or if a systematic (not random) selection of levels of the factor is employed.

7. Cell: Each combination of factor levels which occurs in the study is called a cell.

8. Replication factor: The number of observations or replications made within each cell is considered to be a factor nested within all other factors and is called the replications factor.

The following assumptions for FANTAB are partially derived from Millman and Glass (1967):

1. All factors must be either completely crossed or nested.
2. A nested factor must have the same number of levels

in each level of the factor in which it is nested.

3. Assumption number two applies to the replications factor; that is, the number of observations is the same in each cell.

4. FANTAB handles from two to four factors.

5. At least two factors must be crossed.

6. A third factor may or may not be nested within either of the first two factors.

7. A fourth factor may or may not be nested within any of the other three. If it is nested within a factor which is already nested, then it is considered to be nested within two factors (a nesting within a nesting).

8. If a factor is nested within two factors, those two factors must not be crossed, with the single exception of the replications factor.

CHAPTER III

USING FANTAB

Input

Given a FANTAB deck or tape and appropriate job cards for starting execution of a program, all that is needed to run FANTAB for a particular case are from four to six data cards. From two to four cards are used to describe the factors of the design. Two other cards describe the replications factor and signal the end of the set of factor cards. In the first column of each "factor card" is put any letter other than the letter "R" that the user wishes to have designate the factor. Each factor must be designated by a different letter. The first two cards must not be nested factors. If a factor is nested within one other factor, a colon appears in column two and the letter which designates the other factor appears in column three. If a factor is nested within two other factors, both of these factors appear in columns three and four after a colon in column two, and the card which describes the factor given in column three must be shown to be nested within the factor given in column four.

In column seven of each "factor card" is put a letter R, F, or X (for random, finite, or fixed), depending on which type of factor that card describes. The replications factor is always considered random.

The replications factor card contains the letter R in column one, a colon in column two, the letters which designate the other factors in columns three and four (and five and six, if needed), and the letter R in column seven. The last card always contains the word "TOTAL" in the first five columns. In columns eight through eleven are either the word "HALT" or the word "DONE". "HALT" is used if another set of factor cards is to be considered during the same running of FANTAB. "DONE" is used on the last card of the last set to be considered. If only one set is being used, then "DONE" must be used. Several examples of input data cards are provided in Appendix I.

The FANTAB Program

A listing of FANTAB, including its three subroutines, follows on pages eleven through thirty. The program is well interspersed with comment cards for those who would wish to study the program itself.

Output

The first page of FANTAB's output is a checklist of factor names and types. If names and factor types do not

appear, then a mistake has been made in keypunching the factor cards. Certain checks have been built into the program to catch errors. If the second page of output consists of the sentence "THERE IS A MISTAKE IN YOUR DATA CARDS", then indeed there is. If this is the case, no further output will be present for that particular set of factor cards. If no errors are made, the following elements of the anova table will be produced in this order: sources of variation, sums of squares, degrees of freedom, mean squares, expected mean squares, and F-ratios.

Notation provided by FANTAB appears different at first, but it is completely analogous to that used by Millman and Glass (1967). Notation examples appear in Appendix II, and the reasoning behind them is discussed here. The notation for sources is the same as that used for input with the addition that an interaction of factors is denoted by a combination of letters such as AB, BCD, AC:B. When a colon appears in an interaction, it denotes a nesting of one or more of the factors to the left of the colon within one or more of the factors to the right of the colon.

In several of the formulae, letters are used as subscripts or as symbols to denote the number of levels within a factor (instead of denoting the factor itself). The letter is always the same as the factor name, but of course stands for a subscript or a number. This is necessary because certain computers can not print lower case letters,

which are usually used for subscripts and upper limits of summations. Also, since the summation sign (Σ) and the "sigma-square" (σ^2) notation for variance do not exist in Fortran IV, an ampersand (&) and a dollar sign (\$) have been substituted. The lower limits of summation signs are slightly redundant since each lower limit is one. They have been deleted in FANTAB to make sums of squares formulae more readable. Sometimes a sum of squares term is broken at the end of a line of output. Continuation to the next line should be assumed.

The subscripts for X , the general observation, are also redundant and are deleted. Where fixed factors cause changes in certain terms of expected mean squares, a double dollar sign (\$\$) notation is used to denote a whole sequence of characters instead of having a whole clutter of expressions. Even though FANTAB's notation is shorter, there is no ambiguity! See the examples listed in Appendix II.

LEVEL 21

MAIN

DATE = 7/14/1

117

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C
C FANTAB IS A PROGRAM WHICH HELPS DESIGN FACTORIAL ANALYSIS OF
C VARIANCE TABLES AND PROVIDES FORMULAE FOR TABLE ENTRIES.
C
C FANTAB IS APPROPRIATE FOR FACTORIAL MODELS WHICH HAVE 2,3,OR 4
C FACTORS, WHICH MAY BE RANDOM, FINITE, OR FIXED, AND SOME OF
C WHICH MAY BE NESTED (AS OPPOSED TO CROSSED).
C
      IMPLICIT INTEGER (A-Z)
      DIMENSION A1(17,4),A2(17,50),A3(17,50),A4(17,550)
      X,A6(17,20),R1(10),TYPE(6),F(6,6),A5(17,100)
      DATA PLUS,MINUS,MULT,DIVIDE,LPAREN,RPAREN,EQUAL,RELAX,DEL,
      XCOLON,SUMAT/'+', '-', '*', '/', '(', ')', '=', '!', ':', 'E' /
      X,HALT,ONE,DONE,AREZ/HAUT', '1', 'DONE', '0' /
      1 FORMAT(6A),A1,A4)
      2 FORMAT (1H1,'THERE IS A MISTAKE IN YOUR DATA CARDS,1)
      3 FORMAT(1H1,////,9X,'THE FACTORS ARE:',5X,'THE TYPES ARE:')
      4 FORMAT (1H0,18X,A1,18X,A1)
      5 FORMAT (1H0,/,15X,A1)
      6 FORMAT (1H0,/,15X,A1)
      7 FORMAT (1H0,/,15X,A1)
      8 FORMAT (1H1,///,15X,'SOURCES',/)
      9 FORMAT (1H1,///,15X,'DEGREES OF FREEDOM',/)
      10 FORMAT(1H0,///,15X,'SUM OF SQUARES FOR SOURCE ',A1,/,15X
      X,'EQUALS THE FOLLOWING:',/)
      11 FORMAT (1H1,///,15X,'MEAN SQUARES = SS/DF FOR EACH SOURCE')
      12 FORMAT (1H1,///,15X,'EXPECTED MEAN SQUARES',/)
      13 FORMAT (1H1,///,15X,'F-RATIOS',/)
      14 FORMAT (1H0,15X,A1)
      15 FORMAT (1H1,///,15X,'SUMS OF SQUARES',/)
      16 FORMAT (1H ,14X,A1)
      17 FORMAT (1H0,14X,A1)
      18 FORMAT (1H0,/,15X,20A1)
C
C THIS PART BLANKS ALL APPAYS
C
      34 DO 35 I=1,6
          TYPE(I)=BLANK
          DO 35 J=1,6
      35 F(I,J)=BLANK
          DO 36 I=1,10
      36 R1(I)=BLANK
          DO 37 I=1,17
          DO 38 J=1,8
      38 A1(I,J)=BLANK
          DO 39 J=1,100
      39 A5(I,J)=BLANK
          DO 39 J=1,20
      39 A6(I,J)=BLANK

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      DO 40 J=1,50
      A2(I,J)=BLANK
40  A3(I,J)=BLANK
      DO 37 J=1,550
      A4(I,J)=BLANK
      DO 42 I=1,6
      READ (5,1) (F(I,J),J=1,6),TYPE(I),TEST
      IF (TEST.EQ.HALT) GO TO 43
      IF (TEST.EQ.DONE) GO TO 43
42  K=I
      GO TO 999R
43  WRITE (6,3)
      W=K+1
      DO 41 I=1,K
41  WRITE (6,5)((F(I,J),J=1,6),TYPE(I))
      IF (F(I,2).EQ.COLON) GO TO 999R
      IF (F(I,2).EQ.COLON) GO TO 999R
      IF (K.LT.3) GO TO 999R
      IF (K.GT.5) GO TO 999R
      IF (TYPE(K).NE.ARE) GO TO 999R
C
C K=NO. OF FACTORS INCLUDING R
C
C
C THIS PART GIVES THE MAIN EFFECTS SOURCES
C
      K1=K-1
      DO 50 I=1,K1
      DO 50 J=1,6
      50 A1(I,J)=F(I,J)
C
C THIS PART GIVES DFS FOR MAIN EFFECTS
C
      DO 166 I=1,K1
      A2(I,1)=LPAREN
      A2(I,2)=F(I,1)
      A2(I,3)=MINUS
      A2(I,4)=ONE
      A2(I,5)=RPAREN
      IF (F(I,2).EQ.COLON) GO TO 77
      GO TO 78
77  A2(I,6)=F(I,3)
      IF (F(I,4).EQ.BLANK) GO TO 78
      A2(I,7)=F(I,4)
78  DO 79 J=1,20
79  A3(I,J)=A2(I,J)
      IF (A3(I,7).NE.BLANK) GO TO 161
      IF (A3(I,6).NE.BLANK) GO TO 162

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      GO TO 166
161 A3(I,3)=A3(I,6)
      A3(I,4)=A3(I,7)
      A3(I,5)=MINUS
      A3(I,3)=RPAREN
      GO TO 166
162 A3(I,3)=A3(I,6)
      A3(I,4)=MINUS
      A3(I,5)=A3(I,6)
      A3(I,6)=RPAREN
166 CALL SS(I,A3,A4,K,F)
C
C
C
C THIS SHOULD COMPLETE MAIN EFFECTS
C
C
C THIS PART GIVES THE FIRST ORDER INTERACTION SOURCES
C
      I=K
      DO 54 K3=1,3
      DO 54 K4=2,4
      IF (K3.EQ.K4) GO TO 54
      IF (K3.GT.K4) GO TO 54
      IF (K1.EQ.3.AND.K4.EQ.4) GO TO 54
      IF (K1.EQ.3.AND.K3.EQ.3) GO TO 71
      R1(1)=F(K3,1)
      R1(2)=F(K4,1)
      IF (F(K3,2).EQ.COLON) GO TO 100
      IF (F(K4,2).EQ.COLON) GO TO 102
      GO TO 51
100 R1(3)=COLON
      R1(4)=F(K3,3)
      IF (F(K3,4).NE.BLANK) GO TO 105
      IF (F(K4,2).EQ.COLON) GO TO 104
      GO TO 51
102 R1(3)=COLON
      R1(4)=F(K4,3)
      R1(5)=F(K4,4)
      GO TO 51
104 R1(5)=F(K4,3)
      R1(6)=F(K4,4)
      GO TO 51
105 R1(5)=F(K3,4)
      51 DO 53 I2=1,6
      53 A1(I,I2)=R1(I2)
C
C THIS PART ELIMINATES CERTAIN INTERACTIONS DUE TO ABSTINGS

```

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MAIN

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C

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IF (A1(I,3).EQ.COLON.AND.A1(I,1).EQ.A1(I,4)) GO TO 996
IF (A1(I,3).EQ.COLON.AND.A1(I,1).EQ.A1(I,5)) GO TO 996
IF (A1(I,3).EQ.COLON.AND.A1(I,1).EQ.A1(I,6)) GO TO 996
IF (A1(I,3).EQ.COLON.AND.A1(I,2).EQ.A1(I,4)) GO TO 996
IF (A1(I,3).EQ.COLON.AND.A1(I,2).EQ.A1(I,5)) GO TO 996
IF (A1(I,3).EQ.COLON.AND.A1(I,2).EQ.A1(I,6)) GO TO 996

```

C

C THIS PART GIVES DES FOR 1ST ORDER INTERACTIONS

C

```

A2(I,1)=LPAREN
A2(I,2)=F(K3,1)
A2(I,3)=F(K4,1)
A2(I,4)=MINUS
A2(I,5)=E(K3,1)
A2(I,6)=MINUS
A2(I,7)=F(K4,1)
A2(I,8)=PLUS
A2(I,9)=ONE
A2(I,10)=RPAREN
IF (F(K3,2).EQ.COLON) GO TO R0
IF (F(K4,2).EQ.COLON) GO TO R2
GO TO 55
R0 A2(I,11)=F(K3,3)
IF (F(K3,4).EQ.BLANK) GO TO R4
A2(I,12)=F(K3,4)
R1 IF (F(K4,2).EQ.COLON) GO TO R3
GO TO 55
R2 A2(I,11)=F(K4,3)
IF (F(K4,4).EQ.BLANK) GO TO 55
A2(I,12)=F(K4,4)
R3 A2(I,13)=F(K4,3)
GO TO 55
R4 A2(I,12)=F(K4,3)
A2(I,13)=F(K4,4)

```

C

C

```

55 DO 56 J=1,20
56 A3(I,J)=A2(I,J)
IF (A3(I,12).NE.BLANK) GO TO 163
IF (A3(I,13).NE.BLANK) GO TO 164
GO TO 167
163 A3(I,4)=A3(I,11)
A3(I,5)=A3(I,12)
A3(I,6)=MINUS
A3(I,7)=A3(I,2)
A3(I,8)=A3(I,4)
A3(I,9)=A3(I,5)

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      A3(I,10)=MINUS
      A3(I,11)=A3(I,3)
      A3(I,12)=A3(I,4)
      A3(I,13)=A3(I,5)
      A3(I,14)=PLUS
      A3(I,15)=A3(I,4)
      A3(I,16)=A3(I,5)
      A3(I,17)=RPAPEN
      GO TO 167
164  A3(I,4)=A3(I,11)
      A3(I,5)=MINUS
      A3(I,6)=A3(I,2)
      A3(I,7)=A3(I,4)
      A3(I,8)=MINUS
      A3(I,9)=A3(I,3)
      A3(I,10)=A3(I,4)
      A3(I,11)=PLUS
      A3(I,12)=A3(I,4)
      A3(I,13)=RPAPEN
167  CALL SS(I,A3,A4,K,F)
      I=I+1
      IF (K1.EQ.2) GO TO 71
      GO TO 54
996  DO 997 IS=1,8
997  A1(I,IS)=PLANK
54  CONTINUE
C
C THIS PART ELIMINATES CERTAIN INTERACTIONS DUE TO NESTINGS
C
      IF (K1.EQ.4.AND.I.EQ.8) GO TO 71
      IF (K1.EQ.3.AND.I.LT.6) GO TO 71
C
C
C THIS SHOULD COMPLETE FIRST ORDER INTERACTIONS
C
C
C THIS PART GIVES THE SECOND ORDER INTERACTION SOURCES
C
C
C I= THE NUMBER OF SOURCES THUS FAR PLUS ONE
C
      DO 59 K6=1,2
      DO 59 K7=2,3
      DO 59 K8=3,4
      IF (K7.EQ.K8) GO TO 59
      IF (K6.EQ.K7) GO TO 59
      R1(1)=F(K6,1)
      R1(2)=F(K7,1)

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      F1(3)=F(KR,1)
      IF (F(K7,2).EQ.COLON) GO TO 60
      IF (F(K8,2).EQ.COLON) GO TO 62
      GO TO 57
60 R1(4)=COLON
      R1(5)=F(K7,3)
      IF (F(K7,4).NE.BLANK) GO TO 64
      IF (F(KR,2).EQ.COLON) GO TO 65
      GO TO 57
62 R1(4)=COLON
      R1(5)=F(K8,3)
      R1(6)=F(KR,4)
      GO TO 57
64 R1(6)=F(K7,4)
      IF (F(K8,2).EQ.COLON) F1(7)=F(KR,3)
      GO TO 57
65 R1(6)=F(KR,3)
      R1(7)=F(KR,4)
57 DO 58 IZ=1,7
58 A1(I,IZ)=R1(IZ)

```

C

C THIS PART ELIMINATES CERTAIN INTERACTIONS DUE TO RESTINGS

C

```

      IF (A1(1,4).EQ.COLON.AND.A1(1,1).EQ.A1(1,5)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,1).EQ.A1(1,6)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,1).EQ.A1(1,7)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,2).EQ.A1(1,5)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,2).EQ.A1(1,6)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,2).EQ.A1(1,7)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,3).EQ.A1(1,5)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,3).EQ.A1(1,6)) GO TO 994
      IF (A1(1,4).EQ.COLON.AND.A1(1,3).EQ.A1(1,7)) GO TO 994

```

C

C THIS PART GIVES DFS FOR 2ND ORDER INTERACTIONS

C

```

      A2(1,1)=LPAPEN
      A2(1,2)=F(K6,1)
      A2(1,3)=F(K7,1)
      A2(1,4)=F(K8,1)
      A2(1,5)=MINUS
      A2(1,6)=F(K6,1)
      A2(1,7)=F(KR,1)
      A2(1,8)=MINUS
      A2(1,9)=F(K7,1)
      A2(1,10)=F(K8,1)
      A2(1,11)=PLUS
      A2(1,12)=F(KR,1)
      A2(1,13)=MINUS

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A2(I,14)=F(K6,1)
A2(I,15)=F(K7,1)
A2(I,16)=PLUS
A2(I,17)=F(K6,1)
A2(I,18)=PLUS
A2(I,19)=F(K7,1)
A2(I,20)=MINUS
A2(I,21)=ONE
A2(I,22)=RPAREN
IF (F(K7,2).EQ.COLON) GO TO 66
IF (F(K8,2).EQ.COLON) GO TO 67
GO TO 70
66 A2(I,23)=F(K7,3)
IF (F(K7,4).EQ.BLANK) GO TO 69
A2(I,24)=F(K7,4)
IF (F(K8,2).EQ.COLON) GO TO 68
GO TO 70
67 A2(I,23)=F(K8,3)
IF (F(K8,4).EQ.BLANK) GO TO 70
A2(I,24)=F(K8,4)
68 A2(I,25)=F(K8,3)
GO TO 70
69 A2(I,24)=F(K8,3)
A2(I,25)=F(K8,4)
70 DO 72 J=1,30
72 A3(I,J)=A2(I,J)
IF (A3(I,23).NE.BLANK) GO TO 165
GO TO 169
165 A3(I,5)=A3(I,23)
A3(I,6)=MINUS
A3(I,7)=A3(I,2)
A3(I,7)=A3(I,2)
A3(I,8)=A3(I,4)
A3(I,9)=A3(I,5)
A3(I,10)=MINUS
A3(I,11)=A3(I,3)
A3(I,12)=A3(I,4)
A3(I,13)=A3(I,5)
A3(I,14)=PLUS
A3(I,15)=A3(I,4)
A3(I,16)=A3(I,5)
A3(I,17)=MINUS
A3(I,18)=A3(I,2)
A3(I,19)=A3(I,3)
A3(I,20)=A3(I,5)
A3(I,21)=PLUS
A3(I,22)=A3(I,2)
A3(I,23)=A3(I,5)

```

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      A3(I,24)=PLUS
      A3(I,25)=A3(I,3)
      A3(I,26)=A3(I,5)
      A3(I,27)=MINUS
      A3(I,28)=A3(I,5)
      A3(I,29)=RPAREN
168 CALL SS(I,A3,44,K,F)
      I=I+1
      IF (K1.EQ.3) GO TO 71
      GO TO 69
994 DO 995 I3=1,8
995 A1(I,I3)=RIANK
      99 CONTINUE
C
C THIS PART ELIMINATES CERTAIN INTERACTIONS DUE TO NESTINGS
C
      IF (K1.EQ.4.AND.I.LT.14) GO TO 71
C
C THIS SHOULD COMPLETE SECOND ORDER INTERACTIONS
C
C
C THIS PART GIVES THE THIRD ORDER INTERACTION SOURCE
C
      IF (F(3,2),EQ.COLONE) GO TO 71
      IF (F(4,2),EQ.COLONE) GO TO 71
      A1(15,1)=F(1,1)
      A1(15,2)=F(2,1)
      A1(15,3)=F(3,1)
      A1(15,4)=F(4,1)
C
C THIS PART GIVES DFS FOR 3RD ORDER INTERACTION
C
      A3(15,1)=LPAREN
      A3(15,2)=F(1,1)
      A3(15,3)=F(2,1)
      A3(15,4)=F(3,1)
      A3(15,5)=F(4,1)
      A3(15,6)=MINUS
      A3(15,7)=F(1,1)
      A3(15,8)=F(3,1)
      A3(15,9)=F(4,1)
      A3(15,10)=MINUS
      A3(15,11)=F(2,1)
      A3(15,12)=F(3,1)
      A3(15,13)=F(4,1)
      A3(15,14)=PLUS
      A3(15,15)=F(3,1)
      A3(15,16)=F(4,1)

```

LEVEL 21

MAIN

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```

      A3(15,17)=MINUS
      A3(15,18)=F(1,1)
      A3(15,19)=F(2,1)
      A3(15,20)=F(4,1)
      A3(15,21)=PLUS
      A3(15,22)=F(1,1)
      A3(15,23)=F(4,1)
      A3(15,24)=PLUS
      A3(15,25)=F(2,1)
      A3(15,26)=F(4,1)
      A3(15,27)=MINUS
      A3(15,28)=F(4,1)
      A3(15,29)=MINUS
      A3(15,30)=F(1,1)
      A3(15,31)=F(2,1)
      A3(15,32)=F(3,1)
      A3(15,33)=PLUS
      A3(15,34)=F(1,1)
      A3(15,35)=F(3,1)
      A3(15,36)=PLUS
      A3(15,37)=F(2,1)
      A3(15,38)=F(3,1)
      A3(15,39)=MINUS
      A3(15,40)=F(3,1)
      A3(15,41)=PLUS
      A3(15,42)=F(1,1)
      A3(15,43)=F(2,1)
      A3(15,44)=MINUS
      A3(15,45)=F(1,1)
      A3(15,46)=MINUS
      A3(15,47)=F(2,1)
      A3(15,48)=PLUS
      A3(15,49)=ONE
      A3(15,50)=CPAPEN
      CALL SS(I,A3,A4,K,F)
C
C THIS SHOULD COMPLETE THIRD ORDER INTERACTION
C
C
C THIS PART GIVES THE ERROR SOURCE
C
      I=1+1
      71 DO 73 IR=1,6
      73 ALL(I,IR) = F (K,IR)
C
C THIS PART GIVES DFS FOR ERROR
C
      A3(1,1)=LDAPEN

```

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```

      A4(I,2)=F(K,1)
      A3(I,3)=MINUS
      A3(I,4)=ONE
      A3(I,5)=RPAREN
      A3(I,6)=F(1,1)
      A3(I,7)=F(2,1)
      IF(K1,GE,3) A3(I,8)=F(3,1)
      IF(K1,EQ,4) A3(I,9)=F(4,1)
      IF(K1,EQ,4) GO TO 171
      IF (K1,EQ,3) GO TO 170
      A3(I,3)=F(1,1)
      A3(I,4)=F(2,1)
      A3(I,5)=MINUS
      A3(I,6)=A3(I,3)
      A3(I,7)=A3(I,4)
      A3(I,8)=RPAREN
      GO TO 172
170 A3(I,5)=F(2,1)
      A3(I,3)=F(1,1)
      A3(I,4)=F(2,1)
      A3(I,6)=MINUS
      A3(I,7)=A3(I,3)
      A3(I,8)=A3(I,4)
      A3(I,9)=A3(I,5)
      A3(I,10)=RPAREN
      GO TO 172
171 A3(I,5)=F(3,1)
      A3(I,3)=F(1,1)
      A3(I,4)=F(2,1)
      A3(I,6)=F(4,1)
      A3(I,7)=MINUS
      A3(I,8)=A3(I,3)
      A3(I,9)=A3(I,4)
      A3(I,10)=A3(I,5)
      A3(I,11)=A3(I,6)
      A3(I,12)=RPAREN
172 CALL SS(I,A3,A4,K,F)
      I=I+1
      IMAX=I

```

C
C THIS PART GIVES THE TOTAL SOURCE

C
DO 75 I9=1,5
75 A1(I,I9)=F(W,I9)

C
C THIS PART GIVES DFS FOR TOTAL

C
A3(I,1)=LPAREN

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```

A3(I,2)=MINUS
A3(I,3)=ONE
A3(I,4)=PLUS
A3(I,5)=F(K,1)
A3(I,6)=F(1,1)
A3(I,7)=F(2,1)
A3(I,8)=PPAREN
IF (K1.GE.3) A3(I,8)=F(3,1)
A3(I,9)=RPAREN
IF (K1.EQ.4) A3(I,9)=F(4,1)
A3(I,10)=PPAREN
IF (K1.LE.3) A3(I,10)=PLANK
IF (K1.EQ.2) A3(I,9) = PLANK
CALL SS(I,A3,A4,K,F)
WRITE (6,8)
WRITE (6,6) ((A1(I,J),J=1,8),I=1,17)
WRITE (6,15)
DO 890 I=1,3
  IF (I.GT.IMAX) GO TO 899
  WRITE (6,10) (A1(I,J),J=1,8)
890 WRITE (6,14) (A4(I,J),J=1,550)
  IF (I.EQ.IMAX) GO TO 899
  WRITE (6,15)
DO 891 I=4,6
  IF (I.GT.IMAX) GO TO 899
  WRITE (6,10) (A1(I,J),J=1,8)
891 WRITE (6,14) (A4(I,J),J=1,550)
  IF (I.EQ.IMAX) GO TO 899
  WRITE (6,15)
DO 892 I=7,9
  IF (I.GT.IMAX) GO TO 899
  WRITE (6,10) (A1(I,J),J=1,8)
892 WRITE (6,14) (A4(I,J),J=1,550)
  IF (I.EQ.IMAX) GO TO 899
  WRITE (6,15)
DO 893 I=10,12
  IF (I.GT.IMAX) GO TO 899
  WRITE (6,10) (A1(I,J),J=1,8)
893 WRITE (6,14) (A4(I,J),J=1,550)
  IF (I.EQ.IMAX) GO TO 899
  WRITE (6,15)
DO 894 I=13,15
  IF (I.GT.IMAX) GO TO 899
  WRITE (6,10) (A1(I,J),J=1,8)
894 WRITE (6,14) (A4(I,J),J=1,550)
  IF (I.EQ.IMAX) GO TO 899
  WRITE (6,15)
DO 895 I=16,17

```

LEVEL 21

MAIN

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```

      IF (I.GT.IMAX) GO TO 899
      WRITE (6,10) (A1(I,J),J=1,8)
895  WRITE (6,14) (A4(I,J),J=1,550)
899  CONTINUE
      WRITE (6,9)
      WRITE (6,7) ((A3(I,J),J=1,50),I=1,17)
      WRITE (6,11)
      CALL EMS.      (K,F,IMAX,A1,A5,TYPE)
      WRITE (6,12)
      WRITE (6,7)(A5(I,J),J=1,50)
      WRITE (6,16) (A5(I,J),J=51,100)
      DO 900 I=2,IMAX
      WRITE (6,17) (A5(I,J),J=1,50)
900  WRITE (6,16) (A5(I,J),J=51,100)
      CALL RATIDS. (A1,A6,A5,IMAX)
      WRITE (6,13)
      WRITE (6,18) ((A6(I,J),J=1,20),I=1,17)
      IF (TEST.NE.DONE) GO TO 34
      GO TO 9999
9998 WRITE (6,2)
      IF (TEST.NE.DONE) GO TO 34
9999 STOP
      END

```

LEVEL 21

SS

DATE = 76141

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```

SUBROUTINE SS (I,A3,A4,K,F)
  IMPLICIT INTEGER (A-Z)
  C USED TO FIND SUMS OF SQUARES GIVEN DEGREES OF FREEDOM
  DIMENSION A3(17,50),A4(17,550),F(6,6),P1(10)
  DATA PLUS,MINUS,MULT,DIVIDE,LPAREN,RPAREN,EQUAL,BLANK,DOT,
XCOLON,SUMATN/'+', '- ', '* ', '/ ', '( ', ') ', '=' , ' ', ': ', '6' /
  DATA X,TWO,CNE/'X', '2', '1' /
  L=2
  J=1
  C
  C THIS GIVES LIST OF FIRST LETTERS OF SOURCES
  C
    5 DO 6 N=1,K
    6 F1(N)=F(N,1)
    IF (A3(I,L).EQ.MINUS) GO TO 1
    GO TO 8
    1 A4(I,J)=MINUS
    L=L+2
    J=J+1
    GO TO 30
  C
  C THIS PART PUTS BLANKS AND A PLUS SIGN BEFORE NEW TERMS
  C
    3 A4(I,J)=BLANK
    J=J+1
    A4(I,J)=PLUS
    J=J+1
    A4(I,J)=BLANK
    J=J+1
    L=L+1
    GO TO 8
  C
  C THIS PART PUTS BLANKS AND A MINUS SIGN BEFORE NEW TERMS
  C
    4 A4(I,J)=BLANK
    J=J+1
    A4(I,J)=MINUS
    J=J+1
    A4(I,J)=BLANK
    J=J+1
    L=L+1
  C
  C THIS PART DIRECTS TRAFFIC
  C
    8 IF (A3(I,L).EQ.PLUS) GO TO 20
    IF (A3(I,L).EQ.MINUS) GO TO 20
    IF (A3(I,L).EQ.CNE) GO TO 20
    IF (A3(I,L).EQ.RPAREN) GO TO 20

```

LEVEL 21

S

DATE = 76141

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```

      IF (A3(I,L).EQ.BLANK) GO TO 23
C
C THIS PART GIVES SUMMATIONS OUTSIDE OF PARENTHESES
C
      A4(I,J)=A3(I,L)
      DO 7 N=1,K
        7 IF (A4(I,J).EQ.P1(N)) P1(N)=BLANK
          J=J+1
          A4(I,J)=SUMATN
          J=J+1
          L=L+1
          GO TO 8
C
C THIS PART GIVES EXPRESSION WITHIN PARENTHESES
C
      20 G=L-1
      IF (A3(I,G).EQ.ONE) GO TO 23
      30 A4(I,J)=LPAREN
      J=J+1
      DO 21 N=1,K
        IF (R1(N).EQ.BLANK) GO TO 21
        A4(I,J)=R1(N)
        J=J+1
        A4(I,J)=SUMATN
        J=J+1
      21 CONTINUE
C
C THIS PART FINISHES EACH TERM AND SETS UP THE NEXT, IF ANY
C
      A4(I,J)=X
      J=J+1
      A4(I,J)=RPAREN
      J=J+1
      A4(I,J)=MULT
      J=J+1
      A4(I,J)=MULT
      J=J+1
      A4(I,J)=TWO
      J=J+1
      A4(I,J)=DIVIDE
      J=J+1
      H=J
      DO 22 N=1,K
        IF (R1(N).EQ.BLANK) GO TO 22
        A4(I,J)=R1(N)
        J=J+1
      22 CONTINUE
      IF (J.EQ.H) GO TO 27

```

LEVEL 21

SS

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```
      GO TO 26
27  A4(I,J)=ONE
      J=J+1
25  DO 24 N=1,K
24  R1(N)=F(N,1)
      IF (A3(I,L).EQ.PLUS) GO TO 3
      IF (A3(I,L).EQ.MINUS) GO TO 4
      L=L+1
      GO TO 8
23  RETURN
      END
```

LEVEL 21

EMS

DATE = 76141

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```

      SUBROUTINE EMS (K,F,IMAX,A1,A5,TYPE)
      IMPLICIT INTEGER (A-Z)
C  USED TO FIND EXPECTED MEAN SQUARES
      DIMENSION A1(17,8),A5(17,100),A2(17,8),R1(10),R2(10),R3(10)
      X,R5(10),TYPE(6),F(6,6)
      DATA PLUS,MINUS,MULT,DIVIDE,LPAREN,RPAREN,EQUAL,BLANK,DOT,
      XCOLON,SUMATN/'+', '-', '*', '/', '(', ')', '=', ' ', '.', ':', '%',
      X,HALT,ONE,DONE,ARE/'HALT','1','DOE','E'/'
      X,A1,X/'S','X'/'
C
C THIS PART BLANKS A?RAYS
C
      DO 60 I=1,17
      DO 60 J=1,8
      60 A9(I,J)=BLANK
      DO 62 Z=1,10
      R5(Z)=BLANK
      R3(Z)=BLANK
      R2(Z)=BLANK
      62 R1(Z)=BLANK
C
C THIS PART GIVES A LIST OF SOURCES BACKWARDS LESS R AND TOTAL
C
      IM=IMAX-1
      IT=IMAX-2
      DO 2 I=1,IT
      M=1+IT-I
      DO 2 J=1,8
      2 A9(I,J)=A1(M,J)
C
C THIS PART GIVES FIRST TERM OF ALL EMS
C
      DO 4 I=1,IM
      4 A5(I,1)=A1
C
C THIS PART GIVES OTHER TERMS FOR ALL SOURCES
C
      DO 50 I=1,IT
C
C THIS PART GIVES LIST OF LETTERS TO LEFT OF COLON IN THE SOURCE
C UNDER CONSIDERATION
C
      DO 9 L=1,6
      IF (A1(I,L).EQ.BLANK) GO TO 10
      IF (A1(I,L).EQ.COLON) GO TO 10
      R2(L)=A1(I,L)
      9 CONTINUE
      10 CONTINUE

```

LEVEL 21

FMS

DATE = 7/6/61

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C
C THIS PART PUTS BLANKS AND A PLUS SIGN AT THE RIGHT OF 1ST TERM
C

M=2
A5(I,M)=BLANK
M=M+1
A5(I,M)=PLUS
M=M+1
A5(I,M)=BLANK
M=M+1

C
C THIS PART GIVES OTHER TERMS FOR SOURCE BEING CONSIDERED
C

11 DO 20 J=1,IMAX
DO 1 N=1,K
P3(N)=F(N,1)
1 R1(N)=F(N,1)

C
C THIS PART ELIMINATES TERMS WHICH DO NOT CONTAIN THE LETTER(S)
C OF THE SOURCE UNDER CONSIDERATION
C

8 DO 7 IL=1,6
DO 12 IK=1,6
IF (P2(IL).EQ.A9(J,IK))GO TO 7
IF (P2(IL).EQ.BLANK) GO TO 7
12 CONTINUE
GO TO 20
7 CONTINUE

C
C THIS PART MAKES LIST OF COEFFICIENTS FOR TERM BEING CONSIDERED
C

DO 14 NO=1,K
DO 14 N=1,K
IF (A9(J,NO).EQ.R1(N)) P1(N)=BLANK
14 CONTINUE

C
C THIS PART MAKES A LIST OF LETTERS IN TERM SOURCE WHICH ARE NOT
C IN THE SOURCE UNDER CONSIDERATION
C

DO 29 NO=1,K
R5(NO)=A9(J,NO)
DO 29 N=1,K
IF (P5(NO).EQ.A1(I,N))R5(NO)=BLANK
29 CONTINUE

C
C THIS PART ELIMINATES CERTAIN TERMS DUE TO FIXED FACTORS
C

DO 32 N=1,K

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END

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```

      IF (P5(N).EQ.BLANK) GO TO 32
      DO 32 N=1,K
      IF (R5(N).EQ.F(N0.1).AND.TYPE(N0).EQ.X) GO TO 20
      32 CONTINUE
C
C THIS PART GIVES COEFFICIENTS
C
      DO 15 N=1,K
      IF (R1(N).EQ.BLANK) GO TO 15
      A5(I,M)=R1(N)
      M=M+1
      15 CONTINUE
C
C THIS PART CHANGES SOME TERMS DUE TO FIXED FACTORS
C
      DO 37 N=1,K
      IF (A9(J,N).EQ.BLANK) GO TO 37
      DO 37 LN=1,K
      IF (A9(J,N).EQ.R3(LN).AND.TYPE(LN).NE.X) GO TO 33
      37 CONTINUE
      A5(I,M)=AT
      M=M+1
      A5(I,M)=AT
      M=M+1
      GO TO 34
C
C THIS PART COMPLETES TERMS AND SETS UP NEXT TERM, IF ANY
C
      33 A5(I,M)=AT
      M=M+1
      34 DO 18 N=1,6
      IF (A9(J,N).EQ.BLANK) GO TO 19
      A5(I,M)=A9(J,N)
      M=M+1
      18 CONTINUE
      19 A5(I,M)=BLANK
      M=M+1
      DO 22 N=1,6
      IF (A1(I,N).EQ.A9(J,M)) GO TO 22
      GO TO 23
      22 CONTINUE
      GO TO 50
      23 A5(I,M)=PLUS
      M=M+1
      A5(I,M)=BLANK
      M=M+1
      20 CONTINUE
      50 CONTINUE
      70 RETURN
      END

```


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```
G=3+K
A6(I,G)=A1(I,K)
41 CONTINUE
G=G+1
A6(I,G)=RPAPEN
G=G+1
A6(I,G)=DIVIDE
G=G+1
A6(I,G)=M
G=G+1
A6(I,G)=S
G=G+1
A6(I,G)=LPAPEN
G=G+1
DO 47 N=1,6
IF (A1(J,N).EQ.BLANK) GO TO 49
A6(I,G)=A1(J,N)
G=G+1
47 CONTINUE
48 A6(I,G)=RPAPEN
50 CONTINUE
RETURN
END
```

CHAPTER IV

CONCLUSION

It is the hope of this writer that this program will be one step toward a much larger computer program which will finally be able to design experimental models on a conversational basis. FANTAB, it must be remembered, forms only those F-ratios which are entirely appropriate. Millman and Glass (1967, p. 50) mention that "If no appropriate F-ratio exists for testing an effect, approximate methods are sometimes applicable. (See, e.g. Winer, 1962)" Thus it remains for someone to add a program for approximate methods. Also, FANTAB assumes equal sized cells, and therefore, a program covering unequal cells or missing data points is needed. Programs should also be written for simple one-way analysis of variance, randomized blocking, Latin squares, and for combinations of these techniques with factorial models. A way should be found to "marry" design programs such as FANTAB to data handling programs, too.

Thus, it is obvious that FANTAB needs to be expanded upon and improved. It should also be translated into other computer languages and made a part of a more general experimental

design program. Meanwhile, it is hoped that it will help potential users of factorial analysis of variance to design experiments.

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APPENDIX I

INPUT EXAMPLES

Three sample input data card sets are shown on the next three pages. The computer card at the bottom of the page precedes the next one up, etc. It is, of course, only necessary to show the printing at the top of each card to indicate what is punched on that card. The third sample shows how "HALT" is used to obtain more than one design for one running of FANTAB.

APPENDIX II

NOTATION EXAMPLES

1. AD:C means the interaction of A and D, where one is nested within C.
2. R:ABCD means the replication factor in a four factor design.
3. B&(A&C&R&X)**2/ACR means
$$\frac{\sum_i^b \left(\sum_j^a \sum_k^c \sum_l^h X_{ijkl} \right)^2}{acr}$$
4. (AC-A-C+1) means (ac-a-c+1), where lower case letters stand for the number of levels in the source.
5. SS/DF means sum of squares divided by degrees of freedom.
6. \$ + BR\$AC + BCR\$\$A means
$$a-1 + br \sigma_{ac}^2 + br \frac{\sum_i^a \alpha_i^2}{(a-1)}$$
7. CR\$\$AB means
$$cr \frac{\sum_i^a \sum_j^b (\alpha\beta)_{ij}^2}{(a-1)(b-1)}$$
8. MS(AB)/MS(ABC) means the mean square for source AB divided by the mean square for source ABC.

APPENDIX III

OUTPUT EXAMPLES

Five examples of FANTAB's output are below. Please note that the lines of the sources page, degrees of freedom page, expected mean squares page, and F-ratios page line up in each example. The pages may be put side by side, and the degrees of freedom, etc. for each source will line up with the sources. More simply, all entries are put in the same order as sources. There are blank lines under F-ratios where an entirely appropriate F-ratio does not exist. One might note that the letter(s) after the last dollar sign in expected mean squares expressions denote(s) the source also.

The first example (pp. 41-48) shows a two factor design where both factors are random. The second (pp. 49-57) shows a three factor design with all factors random. The third (pp. 58-66) shows a three factor design with two factors fixed, and the third random. Notice the changes this causes in expected mean squares as compared with example two.

The fourth example (pp. 67-78) shows a four factor design with all factors random. The fifth (pp. 79-87) shows a four factor design with nestings. Both a singly and a

doubly nested factor are present. Notice the changes in sources and degrees of freedom as compared with example four. Example four has the largest possible number of sources that can occur in FANTAB (seventeen).

THE FACTORS ARE:

THE TYPES ARE:

A

R

B

Q

R:AB

Q

SOURCES

A

R

AR

R:AB

TOTAL

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE A
EQUALS THE FOLLOWING:

$$AG(BGRGX)^{**2}/BR - (AGBGRGX)^{**2}/ABR$$

SUM OF SQUARES FOR SOURCE B
EQUALS THE FOLLOWING:

$$BG(AERGX)^{**2}/AR - (AGBGRGX)^{**2}/ABR$$

SUM OF SQUARES FOR SOURCE AB
EQUALS THE FOLLOWING:

$$AGBGRGX)^{**2}/P - AG(BGRGX)^{**2}/BR - BG(AERGX)^{**2}/AR \\ + (AGBGRGX)^{**2}/ABR$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE R:AR
EQUALS THE FOLLOWING:

$$R\bar{A}A\bar{R}R\bar{G}(X)^{**2/1} - A\bar{R}R\bar{G}(R\bar{G}X)^{**2/R}$$

SUM OF SQUARES FOR SOURCE TOTAL
EQUALS THE FOLLOWING:

$$-(A\bar{R}R\bar{G}R\bar{G}X)^{**2/AR} + R\bar{A}A\bar{R}R\bar{G}(X)^{**2/1}$$

DEGREES OF FREEDOM

 $(A-1)$ $(B-1)$ $(AB-A-B+1)$ $(RAB-AB)$ $(-1+PAR)$

MEAN SQUARES = SS/DF FOR EACH SOURCE

EXPECTED MEAN SQUARES

$$S + R\&AB + B\&SA$$

$$S + R\&AB + A\&BR$$

$$S + R\&AB$$

$$S$$

F-PATIOS

MS(A)/MS(AB)

MS(R)/MS(AR)

MS(AR)/MS(R:AR)

THE FACTORS ARE:

THE TYPES ARE:

A

R

R

R

C

R

R:ARC

R

SOURCES

A

B

C

AB

AC

BC

ABC

R:ABC

TOTAL

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE A
EQUALS THE FOLLOWING:

$$A\bar{B}(B\bar{C}C\bar{R}R\bar{X})^{**2}/BCR - (A\bar{B}B\bar{C}C\bar{R}R\bar{X})^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE B
EQUALS THE FOLLOWING:

$$B\bar{C}(A\bar{B}C\bar{R}R\bar{X})^{**2}/ACR - (A\bar{B}B\bar{C}C\bar{R}R\bar{X})^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE C
EQUALS THE FOLLOWING:

$$C\bar{R}(A\bar{B}B\bar{C}R\bar{X})^{**2}/ARR - (A\bar{B}B\bar{C}C\bar{R}R\bar{X})^{**2}/ABCR$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE AB
EQUALS THE FOLLOWING:

$$A\&B(C\&R\&X)^{**2}/CR - A\&(B\&C\&R\&X)^{**2}/BCR - B\&(A\&C\&R\&X)^{**2}/ACR + (A\&B\&C\&R\&X)^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE AC
EQUALS THE FOLLOWING:

$$A\&C\&(B\&R\&X)^{**2}/BR - A\&(B\&C\&R\&X)^{**2}/BCR - C\&(A\&B\&R\&X)^{**2}/ABR + (A\&B\&C\&R\&X)^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE BC
EQUALS THE FOLLOWING:

$$B\&C\&(A\&R\&X)^{**2}/AR - B\&(A\&C\&R\&X)^{**2}/ACR - C\&(A\&B\&R\&X)^{**2}/ABR + (A\&B\&C\&R\&X)^{**2}/ABCR$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE ABC
EQUALS THE FOLLOWING:

$$\begin{aligned} & ABCE(RX)^2/R - ACCE(BEREX)^2/RR - BCE(AEREX) \\ & ^2/AR + CE(AEREREX)^2/ARR - ACE(CEREX)^2/CR + \\ & AE(HECEREX)^2/RCR + BE(AECEREX)^2/ACR - (AECER \\ & EX)^2/ABCR \end{aligned}$$

SUM OF SQUARES FOR SOURCE R:ABC
EQUALS THE FOLLOWING:

$$RABCECE(X)^2/1 - ABCE(RX)^2/R$$

SUM OF SQUARES FOR SOURCE TOTAL
EQUALS THE FOLLOWING:

$$-(AECEREX)^2/ABCR + RABCECE(X)^2/1$$

DEGREES OF FREEDOM

$$(A-1)$$

$$(B-1)$$

$$(C-1)$$

$$(AB-A-B+1)$$

$$(AC-A-C+1)$$

$$(BC-B-C+1)$$

$$(ABC-AC-BC+C-AB+A+B-1)$$

$$(RABC-ABC)$$

$$(-1+RABC)$$

MEAN SQUARES = SS/DF FOR EACH SOURCE

EXPECTED MEAN SQUARES

$$S + R\$ABC + BR\$AC + CR\$AB + BCR\$A$$

$$S + R\$ABC + AR\$BC + CR\$AB + ACR\$B$$

$$S + R\$ABC + AR\$BC + BR\$AC + ABR\$C$$

$$S + R\$ABC + CR\$AB$$

$$S + R\$ABC + BR\$AC$$

$$S + R\$ABC + AR\$BC$$

$$S + R\$ABC$$

$$S$$

F-RATIOS

$$MS(AB)/MS(ABC)$$

$$MS(AC)/MS(ABC)$$

$$MS(BC)/MS(ABC)$$

$$MS(ABC)/MS(R:ABC)$$

THE FACTORS ARE: THE TYPES ARE:

A

✕

A

X

5

 $R:ABC$

SOURCES

A

B

C

AB

AC

BC

ABC

D:ABC

TOTAL

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE A
EQUALS THE FOLLOWING:

$$A\bar{A}(B\bar{C}C\bar{R}R\bar{X})^{**2}/ACR - (A\bar{A}B\bar{C}C\bar{R}R\bar{X})^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE B
EQUALS THE FOLLOWING:

$$B\bar{B}(A\bar{C}C\bar{R}R\bar{X})^{**2}/ACR - (A\bar{A}B\bar{C}C\bar{R}R\bar{X})^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE C
EQUALS THE FOLLOWING:

$$C\bar{C}(A\bar{B}B\bar{C}R\bar{X})^{**2}/ABR - (A\bar{A}B\bar{C}C\bar{R}R\bar{X})^{**2}/ABCR$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE AB
EQUALS THE FOLLOWING:

$$A\bar{B}B(C\bar{B}R\bar{E}X)^{**2}/CR - A\bar{B}(B\bar{C}C\bar{E}R\bar{E}X)^{**2}/BCR - B\bar{B}(A\bar{B}C\bar{B}R\bar{E}X)^{**2}/ACR + (A\bar{B}B\bar{C}C\bar{E}R\bar{E}X)^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE AC
EQUALS THE FOLLOWING:

$$A\bar{B}C\bar{C}(R\bar{E}R\bar{E}X)^{**2}/BR - A\bar{B}(B\bar{C}C\bar{E}R\bar{E}X)^{**2}/BCR - C\bar{B}(A\bar{B}B\bar{C}R\bar{E}X)^{**2}/ABR + (A\bar{B}B\bar{C}C\bar{E}R\bar{E}X)^{**2}/ABCR$$

SUM OF SQUARES FOR SOURCE BC
EQUALS THE FOLLOWING:

$$B\bar{C}C\bar{C}(A\bar{B}R\bar{E}X)^{**2}/AR - B\bar{C}(A\bar{B}C\bar{B}R\bar{E}X)^{**2}/ACR - C\bar{B}(A\bar{B}B\bar{C}R\bar{E}X)^{**2}/ABR + (A\bar{B}B\bar{C}C\bar{E}R\bar{E}X)^{**2}/ABCR$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE ABC
EQUALS THE FOLLOWING:

$$A^2B^2C^2(R^2X)^2/R - A^2B^2C^2(R^2EX)^2/RR - B^2C^2(A^2R^2EX)^2/AR + C^2(A^2R^2EX)^2/ARR - A^2B^2(C^2R^2EX)^2/CR + A^2(B^2C^2R^2EX)^2/BCR + B^2(A^2C^2R^2EX)^2/ACH - (A^2B^2C^2R^2EX)^2/ABCR$$

SUM OF SQUARES FOR SOURCE R:ABC
EQUALS THE FOLLOWING:

$$R^2A^2B^2C^2(X)^2/1 - A^2B^2C^2(R^2EX)^2/R$$

SUM OF SQUARES FOR SOURCE TOTAL
EQUALS THE FOLLOWING:

$$-(A^2B^2C^2R^2EX)^2/ABCR + R^2A^2B^2C^2(X)^2/1$$

DEGREES OF FREEDOM

$$(A-1)$$

$$(B-1)$$

$$(C-1)$$

$$(AB-A-B+1)$$

$$(AC-A-C+1)$$

$$(BC-B-C+1)$$

$$(ABC-AC-BC+C-AB+A+B-1)$$

$$(RABC-ABC)$$

$$(-1+RABC)$$

MEAN SQUARES = SS/DF FOR EACH SOURCE

EXPECTED MEAN SQUARES

$$S + BR\$AC + RCR\$\$A$$

$$S + AR\$BC + ACR\$\$R$$

$$S + AR\$C$$

$$S + R\$ABC + CR\$\$AR$$

$$S + RP\$AC$$

$$S + AR\$BC$$

$$S + R\$ABC$$

$$S$$

F-RATIOS

$$MS(A)/MS(AC)$$

$$MS(B)/MS(BC)$$

$$MS(C)/MS(R:ABC)$$

$$MS(AB)/MS(ABC)$$

$$MS(AC)/MS(R:ABC)$$

$$MS(BC)/MS(R:ABC)$$

$$MS(ABC)/MS(R:ABC)$$

THE FACTORS ARE:

THE TYPES ARE:

A

R

B

D

C

Q

D

R

R:ABCD

Q

SOURCES

A

B

C

D

AB

AC

AD

BC

BD

CD

ABC

ABD

ACD

BCD

ABCD

R:ABCD

TOTAL

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE A
EQUALS THE FOLLOWING:

$$A\bar{A}(B\bar{C}\bar{C}D\bar{D}E\bar{E}F\bar{F}X)^2/ABCD - (A\bar{A}B\bar{C}\bar{C}D\bar{D}E\bar{E}F\bar{F}X)^2/ABCD$$

SUM OF SQUARES FOR SOURCE B
EQUALS THE FOLLOWING:

$$B\bar{B}(A\bar{C}\bar{C}D\bar{D}E\bar{E}F\bar{F}X)^2/ACD - (A\bar{A}B\bar{C}\bar{C}D\bar{D}E\bar{E}F\bar{F}X)^2/ABCD$$

SUM OF SQUARES FOR SOURCE C
EQUALS THE FOLLOWING:

$$C\bar{C}(A\bar{B}\bar{B}D\bar{D}E\bar{E}F\bar{F}X)^2/ABD - (A\bar{A}B\bar{C}\bar{C}D\bar{D}E\bar{E}F\bar{F}X)^2/ABCD$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE D
EQUALS THE FOLLOWING:

$$DQ(AEBCDEREX)^2/ABCD - (AEBCDEREX)^2/ABCD$$

SUM OF SQUARES FOR SOURCE AB
EQUALS THE FOLLOWING:

$$ABE(BEBCDEREX)^2/CD - A(BEBCDEREX)^2/BCD - B(BEBCDEREX)^2/ACD + (AEBCDEREX)^2/ABCD$$

SUM OF SQUARES FOR SOURCE AC
EQUALS THE FOLLOWING:

$$ACE(BEBCDEREX)^2/BD - A(BEBCDEREX)^2/BCD - C(BEBCDEREX)^2/ABD + (AEBCDEREX)^2/ABCD$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE AD
EQUALS THE FOLLOWING:

$$ADE(BCEDEX)^2/BCD - AE(BCEDEX)^2/BCD - DE(AEDEX)^2/ABCD + (AECEDEX)^2/ABCD$$

SUM OF SQUARES FOR SOURCE BC
EQUALS THE FOLLOWING:

$$BCE(AEDEX)^2/ABD - BE(AEDEX)^2/ACD - CE(AEDEX)^2/ABD + (AECEDEX)^2/ABCD$$

SUM OF SQUARES FOR SOURCE BD
EQUALS THE FOLLOWING:

$$BDE(AEDEX)^2/ACD - BE(AEDEX)^2/ACD - DE(AEDEX)^2/ABCD + (AECEDEX)^2/ABCD$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE CD
EQUALS THE FOLLOWING:

$$C\bar{D}\bar{D}E(A\bar{B}B\bar{C}E\bar{R}E\bar{X})^{**2}/AB\bar{B} - C\bar{D}\bar{D}E(A\bar{B}B\bar{C}D\bar{E}R\bar{E}X)^{**2}/AB\bar{D}\bar{B} - D\bar{D}\bar{E}(A\bar{B}B\bar{C}E\bar{R}E\bar{X})^{**2}/AB\bar{C}\bar{B} + (A\bar{B}B\bar{C}D\bar{E}R\bar{E}X)^{**2}/AB\bar{C}\bar{D}\bar{B}$$

SUM OF SQUARES FOR SOURCE ABC
EQUALS THE FOLLOWING:

$$A\bar{B}B\bar{C}E\bar{D}E\bar{R}E\bar{X})^{**2}/D\bar{B} - A\bar{B}C\bar{E}(B\bar{E}D\bar{E}R\bar{E}X)^{**2}/B\bar{D}\bar{B} - B\bar{E}C\bar{E}(A\bar{B}D\bar{E}R\bar{E}X)^{**2}/A\bar{D}\bar{B} + C\bar{E}(A\bar{B}B\bar{C}D\bar{E}R\bar{E}X)^{**2}/A\bar{B}\bar{D}\bar{B} - A\bar{B}B\bar{E}(C\bar{E}D\bar{E}R\bar{E}X)^{**2}/C\bar{D}\bar{B} + A\bar{B}(B\bar{E}C\bar{E}D\bar{E}R\bar{E}X)^{**2}/B\bar{C}\bar{D}\bar{B} + B\bar{E}(A\bar{B}C\bar{E}D\bar{E}R\bar{E}X)^{**2}/A\bar{C}\bar{D}\bar{B} - (A\bar{B}B\bar{C}D\bar{E}R\bar{E}X)^{**2}/A\bar{B}\bar{C}\bar{D}\bar{B}$$

SUM OF SQUARES FOR SOURCE ABD
EQUALS THE FOLLOWING:

$$A\bar{B}B\bar{E}D\bar{E}(C\bar{E}R\bar{E}X)^{**2}/C\bar{B} - A\bar{B}D\bar{E}(B\bar{E}C\bar{E}R\bar{E}X)^{**2}/B\bar{C}\bar{B} - B\bar{E}D\bar{E}(A\bar{B}C\bar{E}R\bar{E}X)^{**2}/A\bar{C}\bar{B} + D\bar{E}(A\bar{B}B\bar{E}C\bar{E}R\bar{E}X)^{**2}/A\bar{B}\bar{C}\bar{B} - A\bar{B}B\bar{E}(C\bar{E}D\bar{E}R\bar{E}X)^{**2}/C\bar{D}\bar{B} + A\bar{B}(B\bar{E}C\bar{E}D\bar{E}R\bar{E}X)^{**2}/B\bar{C}\bar{D}\bar{B} + B\bar{E}(A\bar{B}C\bar{E}D\bar{E}R\bar{E}X)^{**2}/A\bar{C}\bar{D}\bar{B} - (A\bar{B}B\bar{E}C\bar{E}D\bar{E}R\bar{E}X)^{**2}/A\bar{B}\bar{C}\bar{D}\bar{B}$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE ACD
EQUALS THE FOLLOWING:

$$\begin{aligned} & AECDE(BREX)^2/BR - AED(BECREX)^2/BCR - CED(BE \\ & BREX)^2/ABR + DE(AEBECREX)^2/ABCP - AECDE(BE \\ & CREX)^2/BCR + AE(BECDECREX)^2/BCDR + CE(AEBDECREX \\ & X)^2/ABDR - (AEBECDECREX)^2/ABCDP \end{aligned}$$

SUM OF SQUARES FOR SOURCE BCD
EQUALS THE FOLLOWING:

$$\begin{aligned} & BECDE(AEREX)^2/AR - BED(AECREX)^2/ACR - CED(AE \\ & BREX)^2/ABR + DE(AEBECREX)^2/ABCP - BECDE(AE \\ & CREX)^2/BCR + BE(AECDECREX)^2/BCDR + CE(AEBDECREX \\ & X)^2/ABDR - (AEBECDECREX)^2/ABCDP \end{aligned}$$

SUM OF SQUARES FOR SOURCE ABCD
EQUALS THE FOLLOWING:

$$\begin{aligned} & AEBECDE(RRX)^2/R - AECDE(BREX)^2/RE - BECDE(AE \\ & REX)^2/AR + CED(AEBREX)^2/ABR - AEBECDE(CREX \\ &)^2/CR + AED(BECREX)^2/BCR + BED(AECREX)^2/ \\ & ACP - DE(AEBECREX)^2/ABCP - AEBECDE(DECREX)^2/DR \\ & + AECDE(BDECREX)^2/BCDR + BECDE(AEDREX)^2/ADR - CE \\ & (AEBDECREX)^2/ABDR + AEBECDE(CDECREX)^2/CDP - AE(BE \\ & CDECREX)^2/BCDR - BE(AECDECREX)^2/ACDR + (AEBECDE \\ & CREX)^2/ABCDP \end{aligned}$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE R:ARCD
EQUALS THE FOLLOWING:

$$R(A&B&C&D&E(X)^{*2}/1 - A&B&C&D&E(PEX)^{*2}/P$$

SUM OF SQUARES FOR SOURCE TOTAL
EQUALS THE FOLLOWING:

$$-(A&B&C&D&E(PEX)^{*2}/ARCD + R(A&B&C&D&E(X)^{*2}/1$$

DEGREES OF FREEDOM

$$(A-1)$$

$$(B-1)$$

$$(C-1)$$

$$(D-1)$$

$$(AB-A-B+1)$$

$$(AC-A-C+1)$$

$$(AD-A-D+1)$$

$$(BC-B-C+1)$$

$$(BD-B-D+1)$$

$$(CD-C-D+1)$$

$$(ABC-AC-BC+C-AB+A+B-1)$$

$$(ABD-AD-BD+D-AB+A+B-1)$$

$$(ACD-AD-CD+D-AC+A+C-1)$$

$$(BCD-BD-CD+D-BC+B+C-1)$$

$$(ABCD-ACD-BCD+CD-ABD+AD+BD-D-ABC+AC+BC-C+AB-A-B+1)$$

$$(RABCD-ABCD)$$

$$(-1+RABCD)$$

MEAN SQUARES = SS/DF FOR EACH SOURCE

EXPECTED MEAN SQUARES

$$S + R\$ABCD + BR\$ACD + CR\$ABD + DR\$ABC + BCR\$AD + BDR\$AC + CDR\$AB + BCDR\$A$$

$$S + R\$ABCD + AR\$BCD + CR\$ABD + DR\$ABC + ACR\$BD + ADR\$BC + CDR\$AB + ACDR\$B$$

$$S + R\$ABCD + AR\$BCD + BR\$ACD + DR\$ABC + ABR\$CD + ADR\$BC + BDR\$AC + ABDR\$C$$

$$S + R\$ABCD + AR\$BCD + BR\$ACD + CR\$ABD + ABR\$CD + ACR\$BD + BCR\$AD + ABCR\$D$$

$$S + R\$ABCD + CR\$ABD + DR\$ABC + CDR\$AB$$

$$S + R\$ABCD + BR\$ACD + DR\$ABC + BDR\$AC$$

$$S + R\$ABCD + BR\$ACD + CR\$ABD + BCR\$AD$$

$$S + R\$ABCD + AR\$BCD + DR\$ABC + ADR\$BC$$

$$S + R\$ABCD + AR\$BCD + CR\$ABD + ACR\$BD$$

$$S + R\$ABCD + AR\$BCD + BR\$ACD + ABR\$CD$$

$$S + R\$ABCD + DR\$ABC$$

$$S + R\$ABCD + CR\$ABD$$

$$S + R\$ABCD + BR\$ACD$$

$$S + R\$ABCD + AR\$BCD$$

$$S + R\$ABCD$$

*

F-RATIOS

$$MS(ABC)/MS(ABCD)$$

$$MS(ABD)/MS(ABCD)$$

$$MS(ACD)/MS(ABCD)$$

$$MS(BCD)/MS(ABCD)$$

$$MS(ABCD)/MS(R:ABCD)$$

THE FACTORS ARE:

THE TYPES ARE:

A

P

R

R

C:R

P

D:CR

P

R:ABCD

P

SOURCES

A

B

C:B

D:CB

AB

AC:B

AD:CB

R:ABCD

TOTAL

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE A
EQUALS THE FOLLOWING:

$$A\bar{E}(B\bar{C}C\bar{D}D\bar{E}E\bar{X})^{**2}/BCD\bar{E} - (A\bar{E}B\bar{C}C\bar{D}D\bar{E}E\bar{X})^{**2}/ABCD\bar{E}$$

SUM OF SQUARES FOR SOURCE B
EQUALS THE FOLLOWING:

$$B\bar{E}(A\bar{C}C\bar{D}D\bar{E}E\bar{X})^{**2}/ACD\bar{E} - (A\bar{E}B\bar{C}C\bar{D}D\bar{E}E\bar{X})^{**2}/ABCD\bar{E}$$

SUM OF SQUARES FOR SOURCE C:B
EQUALS THE FOLLOWING:

$$C\bar{E}B\bar{E}(A\bar{C}D\bar{E}E\bar{X})^{**2}/AD\bar{E} - B\bar{E}(A\bar{C}C\bar{D}D\bar{E}E\bar{X})^{**2}/ACD\bar{E}$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE D:R
EQUALS THE FOLLOWING:

$$D\bar{C}C\bar{B}\bar{B}(A\bar{E}R\bar{E}X)^2/AP - C\bar{B}\bar{B}(A\bar{E}D\bar{E}R\bar{E}X)^2/ADP$$

SUM OF SQUARES FOR SOURCE A:B
EQUALS THE FOLLOWING:

$$A\bar{B}\bar{B}C\bar{C}D\bar{E}R\bar{E}X)^2/CDP - A\bar{B}(B\bar{C}C\bar{D}E\bar{R}E\bar{X})^2/BCDP - B\bar{B}(A\bar{B}C\bar{D}E\bar{R}E\bar{X})^2/ACDP + (A\bar{B}\bar{B}C\bar{C}D\bar{E}R\bar{E}X)^2/ABCDP$$

SUM OF SQUARES FOR SOURCE AC:R
EQUALS THE FOLLOWING:

$$A\bar{B}C\bar{B}\bar{B}(D\bar{E}R\bar{E}X)^2/DR - A\bar{B}\bar{B}(C\bar{B}D\bar{E}R\bar{E}X)^2/CDP - C\bar{B}\bar{B}(A\bar{B}D\bar{E}R\bar{E}X)^2/ADP + B\bar{B}(A\bar{B}C\bar{B}D\bar{E}R\bar{E}X)^2/ACDP$$

SUMS OF SQUARES

SUM OF SQUARES FOR SOURCE AD:CR
EQUALS THE FOLLOWING:

$$AEDCEBCE(PEX)^2/R - AECBCE(DEREX)^2/DR - DECCEBCE(\\$$

$$AEREX)^2/AR + CEBCE(ASDEREX)^2/ADF$$

SUM OF SQUARES FOR SOURCE R:ABCD
EQUALS THE FOLLOWING:

$$REAEBCEDE(X)^2/1 - AEBCECEDE(PEX)^2/R$$

SUM OF SQUARES FOR SOURCE TOTAL
EQUALS THE FOLLOWING:

$$-(AEBCECEDE(PEX)^2/ABCDP + REAEBCECEDE(X)^2/1$$

DEGREES OF FREEDOM

$$(A-1)$$

$$(B-1)$$

$$(C-B)$$

$$(D-C-B)$$

$$(A-B-A-B+1)$$

$$(A-C-B-A-B-C-B+1)$$

$$(A-D-C-B-A-C-B-D-C-B+1)$$

$$(PABCD-ABCD)$$

$$(-1+PABCD)$$

MEAN SQUARES = SS/DF FOR EACH SOURCE

EXPECTED MEAN SQUARES

$$S + P\$AD:CR + DR\$AC:B + COR\$AB + RCDR\$A$$

$$S + P\$AD:CR + DR\$AC:B + COR\$AB + AR\$D:CR + ADR\$C:B + ACDR\$H$$

$$S + P\$AD:CR + DR\$AC:B + AR\$D:CR + ADR\$C:B$$

$$S + P\$AD:CR + AR\$D:CR$$

$$S + P\$AD:CR + DR\$AC:B + COR\$AB$$

$$S + P\$AD:CR + DR\$AC:B$$

$$S + P\$AD:CR$$

6

F-RATIOS

$MS(A)/MS(AB)$

$MS(D:CB)/MS(AD:CB)$

$MS(AB)/MS(AC:B)$

$MS(AC:B)/MS(AD:CB)$

$MS(AD:CB)/MS(R:ABCD)$